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Waist-to-height ratio is independently related to whole and central body fat, regardless of the waist circumference measurement protocol, in non-alcoholic fatty liver disease patients

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Keywords
abdominal obesity, body composition, body fat, non-alcoholic fatty liver disease, waist-to-height ratio.

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Abstract

Background: Waist-to-height ratio (WHtR) has been reported as a preferable risk related body fat (BF) marker, although no standardised waist circumference measurement protocol (WCmp) has been proposed. The present study aimed to investigate whether the use of a different WCmp affects the strength of relationship between WHtR and both whole and central BF in non-alcoholic fatty liver disease (NAFLD) patients.
Methods: BF was assessed with dual energy X-ray absorptiometry (DXA) in 28 NAFLD patients [19 males, mean (SD) 51 (13) years and nine females, 47 (13) years]. All subjects also underwent anthropometric evaluation including height and waist circumference (WC) measurement using four different WCmp (WC1, minimal waist; WC2, iliac crest; WC3, mid-distance between iliac crest and lowest rib; WC4, at the umbilicus) and WHtR was calculated using each WC measurements (WHtR1, WHtR2, WHtR3 and WHtR4, respectively). Partial correlations were conducted to assess the relation of WHtR and DXA assessed BF.
Results: All WHtR were particularly correlated with central BF, including abdominal BF ($r = 0.80$, $r = 0.84$, $r = 0.84$ and $r = 0.78$, respectively, for WHtR1, WHtR2, WHtR3 and WHtR4) and central abdominal BF ($r = 0.72$, $r = 0.77$, $r = 0.76$ and $r = 0.71$, respectively, for WHtR1, WHtR2, WHtR3 and WHtR4), after controlling for age, sex and body mass index. There were no differences between the correlation coefficients obtained between all studied WHtR and each whole and central BF variable.
Conclusions: Waist-to-height ratio was found a suitable BF marker in the present sample of NAFLD patients and the strength of the relationship between WHtR and both whole and central BF was not altered by using different WCmp in the present sample of NAFLD patients.

Introduction

Waist-to-height ratio (WHtR) is an index of abdominal obesity initially proposed by Hsieh and Yoshinaga in the 1990s (1,2). At that time, WHtR was suggested to be a better predictor of multiple coronary heart disease risk factors than other obesity and fat distribution indices in both men (1) and women (2). Despite not being accepted consensually (3,4), WHtR was further suggested to be preferable to other indices and clinical assessments, including body mass index (BMI), waist circumference (WC) and waist-to-hip ratio (WHR), for predicting cardiovascular risk factors in different ethnic and age groups [5,6]. WHtR also appeears to be at least similarly associated with abdominal fat as is WC, and better than both BMI and WHR [7,8]. To our knowledge, few studies have focused on non-alcoholic fatty liver disease (NAFLD) patients using WHtR [9,10]. These studies have found rather high WHtR in NAFLD patients [9,10] which is concordant with the increased cardiovascular risk found in NAFLD patients [10–14]. It is therefore of utmost important to establish standardised clinical body composition (BC) surrogates, as well as potential therapy targets, particularly in higher risk subpopulations, such as patients with NAFLD.

Despite being a promising clinical marker of BC [8,15] and related cardiometabolic risk [5], there is still some inconsistency considering the WC measurement protocol (WCmp) used to calculate WHtR [16]. Several WCmp have been proposed by sound authorities, and used by prominent researchers, although scientific rational is lacking to recommend one single protocol [17–19]. The association of WC with cardiometabolic risk is independent of WCmp [19]. However, measurements using different WCmp have different magnitudes and therefore are not interchangeable [19]. Proposed protocols differ mainly on the anatomical landmarks and correspondent measuring sites. WHtR was initially proposed using WC measured at the umbilicus [1,2]. In subjects without diagnosed diseases WHtR calculated using WC measured at the umbilicus was suggested to be preferable for the estimation of both whole and trunk body fat (BF); however, only two WC measurement protocols were tested (narrowest point between the lower costal border and the top of the iliac crest and at the level of the umbilicus) [15]. In a recent review on WHtR [16], the WC as measured midpoint between the lowest rib and iliac crest was found to be used in 50% of the reviewed papers and, for that reason, its routine use was encouraged.

To our knowledge, it is unknown whether the use of different commonly used waist circumferences, with different measuring sites, affects the relationship between WHtR and both whole and central BF content in NAFLD patients. The independent magnitude of such a relationship is also unknown. Therefore, the present study aimed to determine which of the most used WCmp is better for calculating WHtR for use in clinical practice with NAFLD patients as a surrogate for whole and central BF.

Materials and methods

Subjects

The present study was conducted at Exercise and Health Laboratory, from the Interdisciplinary Centre for the Study of Human Performance (Faculty of Human Kinetics, Technical University of Lisbon, Portugal). To be selected for the study, subjects had to be aged >18 years of age without a history of hepatotoxic substances intake (e.g. steroids) and tobacco consumption. Exclusion criteria included alcohol consumption >20 g day^{-1}; the presence of other potential causes for fatty liver disease, including viral hepatitis, auto-immune disease and others; any physical and/or mental disabilities or any condition that constituted an absolute restriction to exercise; or other diagnosed diseases, except for metabolic and cardiovascular disease (insulin resistance, hypertension or dyslipidaemia), with mandatory specific pharmacological therapy. We studied 28 NAFLD patients [19 males, mean (SD) 51 (13) years and nine females, 47 (13) years] who were diagnosed via liver biopsy or ultrasound. Cardiorespiratory fitness was assessed as described previously [20] for characterisation purposes. Subjects were recruited from the outpatient medical departments in Santa Maria Hospital and Curry Cabral Hospital; 59 consecutive patients were selected based on selection criteria; 37 of the selected subjects accepted to participate and 28 were found eligible to enter the study after exclusion criteria were considered. Subjects were taking one or more of the following medications: platelet inhibitors, angiotensin-converting enzyme inhibitors, nitrates, statins, ezetimibe, nicotinic acid and biguanides, with similar use among both sexes. All participants provided their informed consent before being included in the present study and undergoing any study procedure. All methods used in the present study complied with ethics and Portuguese laws and were approved by Faculty of Human Kinetics institutional review board for human studies

Body composition

Body composition was assessed using dual energy X-ray absorptiometry (DXA) (Explorer W, Hologic; Waltham, MA, USA; Fan beam mode) whole body scans and anthropometric measurements. Repeated measurements with DXA in 18 young adults showed a coefficient of variation (CV) of 1.7% for total BF mass and 1.5% for total %BF. All scans were made in the morning after an overnight 12-h fast. Quality control with spine phantom was made every morning, and with step phantom every week. By default, DXA software (QDR, version 12.4; Hologic Inc., Marlborough, MA, USA) estimates the head, trunk, arms and legs, both left and right, and region BC, according to a three-compartment model (fat mass, lean tissue and bone mass). The trunk region of interest (ROI) (CV = 0.5%) includes chest, abdomen and pelvis regions from the scan [21]. All scans analysis were made by the same observer. All scans were submitted to additional analysis by ROI to assess fat content of the abdominal and central abdominal regions (CV = 1.0%) [21]. The upper and lower limits of the abdominal and central abdominal ROI were determined as the upper edge of the second lumbar vertebra to the lower edge of the fourth lumbar vertebra, respectively [22–24]. The lateral limits of the abdominal ROI were determined to include all trunk length but to exclude any upper limb scan area [23,24], whereas the lateral sides of central abdominal ROI were the vertical continuation of the lateral sides of the ribs cage to exclude lateral subcutaneous fat of the trunk, although including anterior and posterior subcutaneous abdominal fat, as well as intra-abdominal fat [22] (Fig. 1). Absolute and relative BF content results were registered to the nearest 0.01 kg and 0.1%, respectively.

Anthropometric measurements consisted of weight, height and BMI, as well as WC and WHtR. Some standardisation procedures were taken into account, as recommended previously [25], to avoid any bias in the measurements; therefore, all WC measurements were made with subjects in a standing comfortable position, in their underwear, in a 12-h fasting state. All WC measurements were made by the same technician, who was a trained level 2 technician, certified by the International Society for the Advancement of Kinanthropometry, using an inelastic flexible metallic tape (W606PM; Lufkin, Vancouver, BC, Canada) parallel to the floor after a tidal exhalation, to the nearest 0.1 cm. The WC measurement sites in the present study were the narrowest torso (WC1) [26,27], also called minimal waist [19], superior border of the iliac crest (WC2) [18,28], midpoint between the lowest rib and iliac crest (WC3) [29] and umbilicus (WC4) [1,2]. These are the most commonly used protocols endorsed by sound authorities in this field [17,19]. Body weight was measured to the nearest 0.1 kg, and height was measured to the nearest 0.1 cm, on a scale with an attached stadiometer (model 770; Seca, Hamburg, Germany), in accordance with a standard protocol [30]. Both weight and height were used to calculate the subjects' BMI (kg m^{-2}]. WHtR was calculated by dividing each WC by the subjects' height [WHtR = WC (cm)/height (cm)]. Because we used four different WCmp for each subject, we calculated four different WHtR using each measured WC. Therefore, WHtR1, WHtR2, WHtR3 and WHtR4 were calculated using WC1, WC2, WC3 and WC4, respectively. We considered a boundary value of 0.5 for the identification of high WHtR [9,31]. All anthropometric measurements were repeated two times and, if the second differed by more than 1 cm (for waist and height measurements) or 0.5 kg (for weight measurement) from the first measurement, a third measurement was carried out. We always considered the result obtained in the second measurement unless a third measurement was carried out. When a third measurement was taken, we considered the mode or, if mode was absent, the median value of all three measurements. By use of this procedure, we aimed to always use the most suitable value that was actually measured on the subjects (instead of mean values).

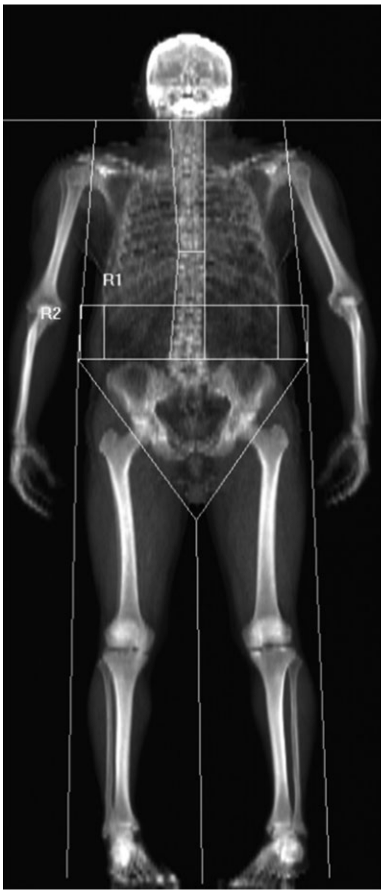

Figure 1 Image of a dual energy X-ray absorptiometry scan showing the abdominal region of interest (R2), defined as the area within the upper edge of the second lumbar vertebra, and the lower edge of the fourth lumbar vertebra and central abdominal region of interest (R1), defined as R2 but the vertical sides limited to the continuation of the lateral sides of the ribs cage.

Statistical analysis

Descriptive statistics are presented as the mean (SD) and range for all analysed variables. The Gaussian distribution of the data was assessed with the Shapiro–Wilk goodness-of-fit test. A paired samples *t*-test was used to compare different WHtR. The association of all WHtR with DXA measures was assessed using partial and semipartial correlations [32], controlling for age, sex and BMI. A statistical power of 80% ($\beta = 0.20$) at a significance level of 5% ($\alpha = 0.05$) was considered statistically significant. Consequently, only coefficients of correlation equal or superior to 0.5, corresponding to a large effect size, attained this criteria ($P \leq 0.05$ and $\beta \leq 0.20$) and could be considered significant [this was in accordance with Cohen *et al.* (1983) to ensure that results are unexposed to type I and II errors, despite a rather modest sample size]. Pairs of coefficients of correlation obtained using different WHtR for each DXA measure were compared using a *Z*-statistic to determine whether any WHtR, according to the WC used in its calculation, was more strongly associated with whole and central BF. Statistical calculations were performed using IBM SPSS, version 19 (IBM Corp., Armonk, NY, USA), except for the *Z*-statistic, which was calculated using MEDCALC, version 11.1.1.0 (MedCalc Software, Mariakerke, Belgium).

Results

Mean values for all the studied variables are presented in Table 1. From among the 28 studied NAFLD patients, WHtR above the boundary value of 0.5 was present in almost 100% of the sample, depending on the WCmp used. Results for WC measurements were considered to be different between all studied WCmp (WC4 > WC2 > WC3 > WC1) and the magnitudes of WHtR mean values were also different according to the WC used. Obesity was present in nine subjects (three were female), according to BMI classification, with no differences between sexes in mean BMI ($P = 0.075$ via an independent samples *t*-test).

Table 2 shows the results for partial and semipartial correlations between each WHtR and each whole or

Table 1 Descriptive data fpr the study sample

Variables	NAFLD patients (n = 28)		
	Mean (SD)	Minimum – Maximum	
Age, year (median, year)	49.5 (12.8) (49)	25–68	
Sex, *n*, female (% female)	9 (32.1)		
$VO_{2\ max}$ (mL kg^{-1} min^{-1})	24.9 (6.4)	13.8–38.0	
Type 2 diabetes mellitus, *n* (%)	8 (28.6)		
Insulin resistance, *n* (%)	12 (42.9)		
Anthropometry			
Weight (kg) (CV, %)	87.6 (12.7) (0.07)	66.2–115.8	
Height (cm) (CV, %)	167.2 (9.2) (0.03)	149.5–183.7	
BMI (kg m^{-2}) (% obese)	29.1 (4.0) (32.1)	22.6–42.2	
WC 1 (cm) (CV, %)	100.7 (8.2)‡ (0.45)	86.0–119.8	
WC 2 (cm) (CV, %)	104.8 (10.6)‡ (0.49)	85.3–128.7	
WC 3 (cm) (CV, %)	103.7 (10.4)‡ (0.47)	85.7–129.3	
WC 4 (cm) (CV, %)	106.3 (11.7)‡ (0.73)	86.7–129.1	
WHtR 1 (≥0.5, %)	0.60 (0.07)† (96.4)	0.48–0.75	
WHtR 2 (≥0.5, %)	0.63 (0.08)† (100.0)	0.50–0.82	
WHtR 3 (≥0.5, %)	0.62 (0.08)† (96.4)	0.49–0.81	
WHtR 4 (≥0.5, %)	0.64 (0.09)† (100.0)	0.50–0.85	
Whole and regional body composition			
BF (kg) (%)	27.2 (9.3) [31.31 (8.20)]	13.7–51.2	(18.84–46.28)
FFM (kg) (%)	58.7 (9.1) [68.69 (8.20)]	39.6–77.7	(53.72–81.16)
Trunk BF (kg) (%)	15.2 (5.2) [33.15 (7.65)]	7.4–25.0	(20.87–48.01)
Trunk FFM (kg) (%)	29.9 (3.9) [66.85 (7.65)]	21.1–38.6	(51.99–79.13)
Appendicular BF (kg) (%)	10.8 (4.8) [30.42 (10.39)]	5.2–25.7	(13.63–50.40)
Appendicular FFM (kg) (%)	24.5 (5.1) [69.58 (10.39)]	14.9–34.8	(49.60–86.37)
Abdominal BF (kg) (%)	3.5 (1.2) [37.57 (6.59)]	1.7–6.3	(26.09–49.40)
Central abdominal BF (kg) (%)	2.9 (0.8) [35.82 (5.70)]	1.6–5.0	(24.28–44.64)

BF, body fat; BF, body fat; BMI, body mass index; CV, coefficient of variation; FFM, fat free mass; FFM, fat free mass; HRR1, heart rate recovery at 1 min; HRR2, heart rate recovery at 2 min.; Máx., highest observed value; Min., lowest observed value; WC1, waist circumference measured at narrowest torso; WC2, waist circumference measured at iliac crest; WC3, waist circumference measured at midpoint between lowest rib and iliac crest; WC4, waist circumference measured at the umbilicus; WHtR 1, waist-to-height ratio calculated using waist circumference measured at narrowest torso; WHtR 2, waist-to-height ratio calculated using waist circumference measured at iliac crest; WHtR 3, waist-to-height ratio calculated using waist circumference measured at midpoint between lowest rib and iliac crest; WHtR 4, waist-to-height ratio calculated using waist circumference measured at the umbilicus.

Results are presented as the mean (SD), unless otherwise noted.

†Different from all other WHtR mean values. $P < 0.05$ in paired samples *t*-test.

‡Different from all other WC mean values. $P < 0.05$ in paired samples *t*-test.

Table 2 Partial and semipartial correlations between all studied waist-to-height ratios and body fat content variables

Variables		Whole BF	Trunk BF	Abd BF	C Abd BF	Whole %BF	Trunk %BF	Abd %BF	C Abd %BF
WHtR 1	†	0.49	0.63*	0.81*	0.72*	0.51*	0.56*	0.65*	0.63*
	‡	0.41	0.58*	0.80*	0.72*	0.45	0.51*	0.66*	0.63*
	§	0.22	0.38*	0.70*	0.69*	0.22	0.32	0.54*	0.55*
WHtR 2	†	0.61*	0.73*	0.82*	0.74*	0.56*	0.59*	0.61*	0.61*
	‡	0.48	0.64*	0.84*	0.77*	0.46	0.52*	0.66*	0.63*
	§	0.26	0.43	0.74*	0.74*	0.23	0.32	0.54*	0.55*
WHtR 3	†	0.60*	0.72*	0.83*	0.74*	0.55*	0.59*	0.62*	0.61*
	‡	0.48	0.64*	0.84*	0.76*	0.46	0.52*	0.66*	0.62*
	§	0.25	0.42	0.74*	0.73*	0.22	0.32	0.54*	0.54*
WHtR 4	†	0.59*	0.68*	0.76*	0.68*	0.51	0.53*	0.56*	0.57*
	‡	0.44	0.58*	0.78*	0.71*	0.42	0.45	0.62*	0.60*
	§	0.23	0.38	0.68*	0.67*	0.20	0.27	0.49	0.50*

Abd BF, Abdominal body fat; BF, body fat; C Abd BF, Central abdominal body fat; Trunk BF, Trunk body fat; WHtR 1, waist-to-height ratio calculated using waist circumference measured at narrowest torso; WHtR 2, waist-to-height ratio calculated using waist circumference measured at iliac crest; WHtR 3, waist-to-height ratio calculated using waist circumference measured at midpoint between lowest rib and iliac crest; WHtR 4, waist-to-height ratio calculated using waist circumference measured at the umbilicus.

*Significant for $P < 0.05$ and $\beta = 0.20$.

†Partial correlations between studied WHtR and dependent variables, controlled for age and sex.

‡Partial correlations between studied WHtR and dependent variables, controlled for age, sex and body mass index.

§Semipartial correlations between studied WHtR and dependent variables, adjusted for age, sex and body mass index.

central studied BF depot, controlling for sex, age and BMI. All WHtR were correlated with the studied BF depots, even after adjusting for age, sex and BMI, showing coefficients of correlation magnitudes above 0.5. Coefficients of correlation tended to decrease as control variables were added, particularly when the effect of age, sex and BMI was removed; however, the strength of association remained for abdominal fat depots.

Table 3 shows the results for the comparison (*P*-values) between pairs of competing WHtR coefficients of correlation with each dependent variable, as listed in Table 2. No differences were found between all compared coefficients of correlation.

Discussion

To our knowledge, this is the first report to focus on the strength of correlation between WHtR and BF in NAFLD patients, as well as its variation associated with the different WCmp used to calculate WHtR. Mean WHtR was reasonably high and the prevalence of elevated WHtR, considering the 0.5 boundary value, was very high in the present sample. This was expected because NAFLD patients have high values of WHtR [9,10]. The magnitudes of the WHtR mean values were different according to the WC (WHtR4 > WHtR2 > WHtR3 > WHtR1) used in its calculus, meaning that they are not interchangeable. This may have large implications in clinical practice and data collection and in the interpretation in longitudinal assessments (pre – post), as well as for between-group comparisons. Several previous studies have reported WC magnitudes (the changeable component of WHtR) to be influenced by WCmp [33–35]. It has been proposed that current WC thresholds, generalised using WHO protocol (at the midpoint between lowest rib and iliac crest), could be applied to National Institutes of Health measurements (at the superior border of the iliac crest) [19] because of the small or absent differences, particularly in men, found between measurements using these WCmp [34,35]. As noted, the present study does not confirm such interchangeability when absolute values were taken into account. However, when a dichotomous approach was applied based on the boundary value of 0.5, both WHtR1 and WHtR2 only misclassified one subject (3.6%) at elevated risk compared to WHtR2 and WHtR4, which diagnosed 100% of the sample above the boundary value, and may be considered as support for an interchangeable use of the protocols for WHtR assessment.

In the present sample of NAFLD patients, as expected, WHtR was highly associated with whole and central BF, adjusted for age, sex and BMI. Correlation coefficient magnitudes revealed a large effect size ($r > 0.5$) for central BF depots. The association of WHtR with BC, particularly with central BF, has been reported in diverse groups [7,8] but not in NAFLD patients until now. WHtR was also shown to predict higher cardiometabolic risk better than WC and BMI [5]. The present study showed consistent coefficients of correlation of WHtR and central fat depots, even when BMI was added to age and sex as control variables, meaning that WHtR explains the

Table 3 *Z*-statistic *P*-values for the comparison between the coefficients of correlation obtained in partial and semipartial correlation between the studied waist-to-height ratios and all dependent variables.

		WHtR 1		WHtR 2		WHtR 3		WHtR 4			
		*P**	*P*†	*P**	*P*†	*P**	*P*†	*P**	*P*†		
				0.98	0.99	0.99	1.00	0.89	0.93	%BF	WHtR 1
				0.99	0.99	0.97	0.98	0.76	0.86	Trunk %BF	
				1.00	1.00	1.00	1.00	0.81	0.80	Abd %BF	
				0.98	0.99	0.99	0.99	0.86	0.84	C Abd %BF	
WHtR 2	BF	0.73	0.87			0.99	0.99	0.87	0.92	%BF	WHtR 2
	Trunk BF	0.72	0.86			0.98	0.99	0.75	0.85	Trunk %BF	
	Abd BF	0.66	0.80			0.99	1.00	0.80	0.80	Abd %BF	
	C Abd BF	0.71	0.74			0.97	0.98	0.84	0.83	C Abd %BF	
WHtR3	BF	0.79	0.90	0.94	0.97			0.88	0.93	%BF	WHtR 3
	Trunk BF	0.74	0.87	0.98	0.99			0.73	0.84	Trunk %BF	
	Abd BF	0.65	0.79	0.98	0.99			0.81	0.81	Abd %BF	
	C Abd BF	0.74	0.78	0.96	0.96			0.87	0.85	C Abd %BF	
WHtR4	BF	0.88	0.96	0.85	0.91	0.91	0.94				
	Trunk BF	0.98	0.98	0.70	0.84	0.72	0.85				
	Abd BF	0.72	0.87	0.54	0.68	0.52	0.67				
	C Abd BF	0.95	0.90	0.66	0.65	0.70	0.68				

Abd BF, abdominal body fat; BF, body fat; C Abd BF, central abdominal body fat; trunk BF, Trunk body fat; WHtR 1, waist-to-height ratio calculated using waist circumference measured at minimal waist; WHtR 2, waist-to-height ratio calculated using waist circumference measured at iliac crest; WHtR 3, waist-to-height ratio calculated using waist circumference measured at midpoint between lowest rib and iliac crest; WHtR 4, waist-to-height ratio calculated using waist circumference measured at the umbilicus.

*Comparison between correlation coefficients obtained in partial correlations between different WHtR and all dependent variables, controlled for age, sex and body mass index.

†Comparison between correlation coefficients obtained in semipartial correlations between different WHtR and all dependent variables, controlling for age, sex and body mass index.See bottom-left half for comparisons between coefficients of correlation obtained between WHtRs and obsolute values of body composition; see upper-right half for comparisons between coefficients of correlation obtained between WHtRs and relative values of body composition.

variation of abdominal fat far beyond BMI. This relationship was already found in subjects without NAFLD, although with no control variables included in the analysis [(15)]. This may explain the marginally lower correlation coefficients found in the present study.

Comparisons between pairs of competing WHtR correlation results with each dependent variable showed that all studied WHtR are similarly associated with the analysed BF depots, irrespective of the WC used for its calculation. Previous studies have already shown no differences in the association of WC alone, measured at different sites, with BF depots [(33,35)]. A recent review concluded that the use of different WCmp does not change the well-established relationships between WC and morbidity of cardiovascular disease and diabetes, as well as cardiovascular and all-cause mortality [(19)]. However, because WHtR have proven to be more sensitive in the prediction of cardiovascular risk, the absence of an influence of WCmp in risk prediction should be confirmed when WC is used to calculate WHtR.

There are several strengths and limitations to the present study. The WCmp investigated do not cover all the protocols existent in the literature, although the focus was on those most commonly employed and endorsed by prominent institutions for use in the clinical setting [(17–19)]. In addition, the assessment method (DXA) used for BC, comprising a gold standard instrument for assessing BC in a three-compartment model, is unable to determine visceral adiposity independent of subcutaneous fat. However, there is a strong correlation between abdominal fat estimated from selected DXA ROI and visceral fat assessed by magnetic resonance imaging [(23)] and computed tomography [(36)]. Patients' physical activity and diet were not assessed; however, patients' cardiorespiratory fitness was assessed, which was low (Table 1), reinforcing the importance of the study of cardiovascular risk related markers in this population [(37)]. Finally, we could not establish the usefulness of WHtR for assessing changes in BF depots based on the present results because we used a cross-sectional approach and therefore no follow-up data are available.

The present study confirms the strong association between WHtR and BF, especially for central BF, even after controlling for age, sex and BMI, in NAFLD patients, supporting WHtR as an independent central obesity index. Moreover, the relationship between WHtR and both whole and central BF was not altered by the choice of a particular

WCmp in the present sample of NAFLD patients. Unlike previous studies in subjects without diagnosed NAFLD [15], we could not recommend the use of one specific WC measurement protocol over another for the calculation of WHtR as a whole and/or central BF surrogate. Thus, the results of the present study may endorse an interchangeable use of different WCmp for identifying a subject's WHtR above the boundary value. Additional research is needed to confirm the influence of different WCmp on the variation of WHtR in specific subpopulations, as well as on the relationship between WHtR and other NAFLD and cardiometabolic risk factors beyond BC alone.

Transparency declaration

The lead author affirms that this manuscript is an honest, accurate and transparent account of the study being reported, that no important aspects of the study have been omitted and that any discrepancies from the study as planned (and registered with) have been explained. The reporting of this work is compliant with Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

Conflict of interests, source of funding and authorship

The authors declare that they have no conflicts of interest.
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NMP, HC-P and HS-C contributed equally to the conception and design of the research. NMP and XM contributed to the acquisition, analysis and interpretation of the data. HC-P and JS-N contributed to the acquisition of data. HS-C contributed to the analysis of data. LBS contributed to the interpretation of the data. NNP drafted the manuscript. All authors critically reviewed the manuscript and approved the final version submitted for publication.

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